SOIL PROPERTIES:
Shear Strength

abg creative geosynthetic engineering

Technical Note

Introduction

The strength of soil is typically defined as the resistance to shear stress in terms of the effective internal friction angle (ϕ') and effective cohesion (c'). This technical note is intended to provide a basis for estimating a soil's unit weight in the absence of specific testing results.

Factors Affecting Soil Shear Strength

The shear strength of a soil is achieved by interaction between the solid, liquid, and gas particles in its make-up. So the shear strength of a soil depends on the composition of the soil's particles, the amount of water in the soil, and how well compacted the soil is. The contributing factors include, but are not limited to:

- Mineralogy of the soil particles (e.g. silica, quartz, feldspar, etc.).
- The range of sizes of the soil particles, also known as the particle size distribution.
- The angularity of the soil particles (most relevant to coarse sands and gravels)
- The moisture content of the soil – whether the voids between the soil particles are completely filled with water (fully saturated) or mostly air – and the capillary forces created by the interaction of the solid particles, water and air.
- Degree of compaction of the soil.

Measuring Soil Shear Strength

The shear strength of a soil is measured directly in a laboratory or estimated from correlations with testing undertaken on site. In a laboratory, shear strength is measured by shear box or triaxial testing in accordance with BS 1377-7:1990 or BS 1377-8.:1990 respectively. On site the most common technique is the correlation between shear strength and SPT (Standard Penetration Test) results. However, there are a wide variety of correlations that can be used to estimate soil strength parameters such as CPT (Cone Penetration Test), DCP (Dynamic Cone Penetrometer), HSV (Hand Shear Vane), Mexe Probe, DMT (Flat Dilatometer Test), etc.

Typical Soil Shear Strengths Parameters

Typical shear strength parameters for various soils have been estimated by several sources depending on the amount of information available. Broadly speaking, information about the soil, and the method of estimating shear strength falls into one of two categories:

1. Information limited to soil type – in the absence of any in-situ testing, such as when a site investigation has not yet been conducted, ABG recommends the correlations from Oritz (Oritz et al., 1986). This information has been reproduced in Table 1, below.
2. Limited Testing Information – a typical site investigation will provide a lot of useful information but may not include any direct measurements of soil strength information. In this case ABG recommends using the advice in BS 8002:2015, and BS EN 1997-2. This information has been reproduced below in (Tables 2, 3 & 4). Alternatively, the 'Handbook of geotechnical investigation and design tables' (Look, 2007) contains a wide variety of useful correlations with a wide range of common geotechnical tests.

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Table 1: Typical soil shear strength based on soil type

	Effective Friction Angle, ϕ' (°)		Effective Cohesion, c' (kPa)
	Peak	Residual	
Gravel	34	32	-
Gravel, sandy with few fines	35	32	-
Gravel, sandy with silty or clayey fines	35	32	1.0
Gravel and Sand mixture, with fines	28	22	3.0
Sand, uniform, fine grained	32	30	-
Sand, uniform, coarse grained	34	30	-
Sand, well graded	33	32	-
Silt, low plasticity	28	25	2.0
Silt, medium to high plasticity	25	22	3.0
Clay, low plasticity	24	20	6.0
Clay, medium plasticity	20	10	8.0
Clay, high plasticity	17	6	10.0
Organic Silt or Clay	20	15	7.0

Table 2: Sands and Gravels - Determination of soil shear strength parameters (BS 8002:2015)

Shear Strength Parameter	Equation
Characteristic peak effective friction angle	$\varphi'_{pk,k} = 30° + \varphi'_{ang} + \varphi'_{PSD} + \varphi'_{dil}$
Characteristic constant volume effective friction angle	$\varphi'_{cv,k} = 30° + \varphi'_{ang} + \varphi'_{PSD}$
Characteristic constant volume effective cohesion	$c'_{cv,k} = 0\ kPa$

Soil Property	Determined from	Classification	Parameter [D]
Angularity of particles [A]	Visual description of soil	Rounded to well-rounded	$\phi'_{ang} = 0°$
		Sub-angular to sub-rounded	$\phi'_{ang} = 2°$
		Very angular to angular	$\phi'_{ang} = 4°$
Uniformity coefficient, C_u [B]	Soil grading	$C_u < 2$ (evenly graded)	$\phi'_{PSD} = 0°$
		$2 \leq C_u < 6$ (evenly graded)	$\phi'_{PSD} = 2°$
		$C_u \geq 6$ (medium to multi graded)	$\phi'_{PSD} = 4°$
		High C_u (gap graded), with C_u of fines < 2 [E]	$\phi'_{PSD} = 0°$
		High C_u (gap graded), with $2 \leq C_u$ of fines < 6 [E]	$\phi'_{PSD} = 2°$
Density index, I_D [C]	Standard penetration test blow count, corrected for energy rating and overburden pressure $(N_1)_{60}$	$I_D = 0\%$	$\phi'_{dil} = 0°$
		$I_D = 25\%$	$\phi'_{dil} = 0°$
		$I_D = 50\%$	$\phi'_{dil} = 3°$
		$I_D = 75\%$	$\phi'_{dil} = 6°$
		$I_D = 100\%$	$\phi'_{dil} = 9°$

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Notes for Table 2:

A) Terms for defining particle shape can be found in BS EN ISO 14688-1.
B) The uniformity coefficient C_u is defined in BS EN ISO 14688-2
C) The density index /D is defined in BS EN ISO 14688-2. Density terms may be estimated from the results of field tests (e.g. Standard Penetration Test, Cone Penetration Test) using correlations given in BS EN 1997-2:2007.
D) Values of <p'M are appropriate for siliceous sands and gravels reaching failure at a mean effective stress up to 400 kPa. For non-siliceous sands, see BS 8002:2015
E) "Fines" refers to that fraction of the soil whose particle size is less than 0.063 mm.

Table 3: Sands and Gravels – Correlation between normalised blow count and density index (BS EN 1997-2:2007)

	Very Loose	Loose	Medium	Dense	Very Dense
Standard Penetration Test normalised blow counts, $(N_1)_{60}$	0 – 3	3 – 8	8 – 25	25 – 42	42 – 58
Density Index, I_D	0% – 15%	15% – 35%	35% – 65%	65% – 85%	85% – 100%

Note:
For fine sands, the N-values should be reduced in the ratio 55:60 and for coarse sands increased in the ratio 65:60

Table 4: Silts and Clays - Determination of soil shear strength parameters (BS 8002:2015)

Plasticity Index, I_P (%)	Characteristic constant volume effective friction angle $\phi'_{cv,k}$
15	27°
30	24°
50	21°
80	18°

Note:
The characteristic constant volume effective cohesion (c'_{cvk}) should be taken as zero

References

British Standards Institution, BS 1377-7:1990 - Methods of test for soils for civil engineering purposes. Shear strength tests (total stress)

British Standards Institution, BS 1377-8:1990 - Methods of test for soils for civil engineering purposes. Shear strength tests (effective stress)

British Standards Institution, BS 8002:2015 - Code of Practice for Earth Retaining Structures

British Standards Institution, BS EN 1997-2:2007 – Eurocode 7 – Geotechnical design Part 2: Ground investigation and testing

Look, B. (2007). Handbook of geotechnical investigation and design tables. London: Taylor & Francis.

Ortiz et al. (1986).

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